of the opium dream. We first saw it unfolding its curling, scimetar-like leaves in the chilly upper air; then we passed on every hand its gorgeous nodding flowers; and lower down, their work done, the petals were falling and the pale green serpent's head stood up naked, not ugly in itself, but hideous in its potency of evil.

In the valley of the Pu-ho there was a well-established foot-path, suitable even for pack animals, and our difficulties were over when we crossed the summit. The way was easy to the Han River, which we reached at the walled city of Shï-chuan-hien, one hundred and ten miles from Chou-chlï-hien. We had crossed in twenty days, at a most unfavourable season, with many delays occasioned by weather and high water. Nowhere had we met with any real difficulty, and, judging by the accounts given by von Richthofen and others of the cañons through which the great southwestern highway between the Wei valley and Sze-chwan is built, the route which it takes offers much more formidable obstacles to the passage of the range than any we encountered. The pass we crossed and the approaches to it are entirely practicable for railway construction, and it is quite possible that still better ways might be found. The rocks above the active work of running streams are somewhat decayed and often soil-covered, yet firm underneath. When, in the development of the Chinese Empire, it becomes necessary to connect the valley of the Wei with that of the upper Han River at Han-chung-fu, there will be no difficulty in building that section of the great southwestern trunk line, even across the barriers of the Ts'in-ling-shan.

CERTAIN RELATIONS OF RAINFALL AND TEMPERATURE TO TREE GROWTH.

BY

HENRY GANNETT.

Of the various factors, climatic and otherwise, which affect the growth of forests and different species of trees, there are two which are of a primary character. These are annual temperature and annual rainfall—that is, the amount of heat and the amount of water. These two factors determine whether trees can grow, and if so, what species.

There are numerous other factors which have a modifying effect, among which are seasonal temperatures, seasonal rainfall,

humidity of the air, evaporation, wind exposure, slope exposure, degree of slope, and soil texture and depth.

The roots of trees penetrate into the soil to such a depth that they are not affected by ordinary droughts. Whether a season is dry or wet matters little so long as the year's precipitation is sufficient. Trees are hardy plants, as a rule, and are not affected by short periods of extreme heat and cold. Hence, seasonal variations, either of rainfall or temperature, have little effect upon them. That this is true in regard to rainfall is shown by the fact that yellow pine flourishes upon the slopes of the Sierra, where most of the rain comes in the winter, and also upon the Colorado plateau in Arizona, where most of it comes in the summer.

Exposure to wind has, of course, a modifying influence in the distribution of trees, especially on high mountains; but it is not a determining factor. The timber-line is not caused by wind; if it were, trees would extend to the summits of the highest mountains on the leeward side. As it is, the effect of wind and of depth of soil is shown in the elevation or depression of the timber-line for a few hundred feet only.

Near the lower limit of the yellow pine in the Sierra Nevada this tree is seen to extend farther down upon the north slopes of the spurs, and in damp, sheltered places; but the effect of such slope exposure is seen for two hundred, or possibly three hundred, feet only, while the absolute disappearance of yellow pine at certain altitudes in the Sierra is due to some other cause, and certainly not to this or any of the causes above enumerated as secondary. The fact that this line coincides very closely from the north to the south limit of the United States with the isohyetal line of 20 inches is pretty good evidence that it is annual rainfall that induces it, whatever local variations may be introduced by secondary causes.

The fact that under the same rainfall and other conditions different species are found in tropical, temperate, and polar regions is evidence that the annual temperature is the determining factor in such cases.

If the foregoing is conceded, it would seem that the following is the logical order of entering upon the study of the relations of climatic and other conditions to the growth and distribution of trees:

1. The influence of the primary causes as above stated.
2. The modifying influences of the secondary causes.

The present paper is designed to show how much and what

information our present knowledge of the climatic elements develops concerning tree growth in the western United States. The fact that in the matter of temperature only negative results have thus far been reached shows, to my mind, only the imperfections of our knowledge—imperfections which will be remedied by more extended and better-directed observation. In the matter of rainfall it seems to me that certain facts of importance have been developed—that is, the rainfall at the lower limits of forests in general, and of yellow pine, red fir, and redwood.

For several years past the United States Geological Survey and the Forestry Bureau of the Department of Agriculture have been employed in collecting information concerning the distribution of forests in the mountain regions of the West. The former organization has for the past ten years been engaged in the examination of forest reserves and adjacent lands, and in the preparation of land-classification maps of these areas. Furthermore, the topographers of the Survey working in this part of the country have, in addition to the preparation of topographic maps, prepared also land-classification maps.

The Forestry Bureau has in recent years made examinations and prepared reconnoissance maps of large areas which had been withdrawn from settlement with a view to creating forest reserves.

The work of these two organizations taken together covers nearly all the forested land of the West and makes it possible to prepare a map of this part of the country showing the regions which are wooded or forested and the areas occupied by certain kinds of timber.

The distribution of timber generally and of the species above designated, with relation to the two chief elements of climate—temperature and moisture—is a matter of great interest. Knowledge of the limiting temperatures and limiting rainfalls within which timber in general will grow, and within which different species of timber will grow is of first importance in the study of forest environment.

The information concerning climatic elements has been obtained from the Weather Bureau, whose officers have placed at my disposal not only all printed data concerning temperature and rainfall, but all manuscript material in their possession. There are returns from probably one thousand meteorological stations scattered over the Rocky Mountain and Pacific Coast States. After discarding all stations in which the rainfall series is less than five years, I have the records of a little over four hundred stations.

Most of these stations present also a record of temperature, so that the temperature stations are between three and four hundred in number. The distribution of these stations is not, however, by any means what could be desired, the great majority of them being situated in towns and cities, and therefore in low and open or non-timbered country; and very few of them are high up in the mountains, so that in those parts of the West in which the timber is confined to the mountains the timbered regions are not well represented. This is especially true of the Rocky Mountain States, including Montana, Idaho, Wyoming, Utah, Nevada, Colorado, New Mexico, and Arizona. In these States nearly nine-tenths of the stations are in open country, only a few more than one-tenth being situated in the forests. In western Oregon and Washington, where the forests cover the valley lands as well as the mountains, there are naturally many stations in the forests. To a less extent this is true of northern California, but in southern California it is much the same as in the Rocky Mountain States. Hence it is that the information concerning the temperature and rainfall of the forested region in the Rocky Mountain States and southern California is scanty, while in northern California, western Oregon, and Washington it is much more abundant.

The mean annual temperature at any place is fairly constant year by year—that is, the mean temperature of one year differs but little from that of other years; hence it does not require a long period of observation to establish accurately the mean annual temperature at any locality. Moreover, the temperature is not much affected by topographic surroundings, so that the observations made at any place fairly represent the temperature of the neighbouring country. This is not, however, the case with rainfall observations. The surrounding topography, and even the location of the rain-gauge, materially affect the amount of rainfall and the amount of water collected, so that there is no assurance that the rainfall measured at the station represents the rainfall of any considerable area surrounding it. Further, the rainfall of different years differs widely. In a locality twice as much rain may fall in one year as in the year preceding or the year following, and it is only by obtaining the mean of a series of years that one is assured that he has the average rainfall of his station. It is owing to these uncertainties that one must use rainfall measurements with caution and should obtain the mean rainfall of a group of stations as that of a locality, rather than one station alone.

The figures for rainfall and temperature at all of the stations obtained were platted upon Land Office maps of the several States, and the outlines of timber sketched upon the same maps or upon different maps. In this way the location of the different stations was obtained with reference to the forests.

In this study the lands were first classified as *open* or *timbered.* The timbered lands were classified as *yellow pine, red fir, redwood lands,* and *"other timber."* In "other timber" are included lands covered with piñon, juniper, nut pine, and oak, which may be grouped under the designation "desert species."

The stations in each of these classes were taken off the map, with their rainfall and temperature. The average rainfall and temperature of each of these classes of lands was obtained from the figures. The stations were also grouped in each of these classes, the groups being for the temperature each five degrees and for the rainfall each ten inches. The results are set forth in tables:

TEMPERATURE.

States.	Average Temperature in Degrees Fahr.				
	Yellow Pine.	Fir.	Redwood.	Desert Species.	Open Country.
Arizona	54	..	..	62	65
Colorado	..	..	..	..	47
California (North)	51	..	54	61	60
California (South)	..	..	..	57	63
Idaho	..	..	..	..	48
Montana	44	..	..	..	43
New Mexico	..	..	..	52	56
Nevada	..	..	..	.	50
Oregon	50	51	..	..	47
Utah	..	..	..	.	49
Washington	46	50	..	..	48
Wyoming	..	..	..	..	42
Average temperatures of total stations	50	51	54	60	54

RED FIR.

Number of Stations in each Temperature Group.

States.	40°–45°	45°–50°	50°–55°	55°–60°
Washington	..	4	21	1
Oregon	1	..	22	..
Totals	1	4	43	1

OPEN COUNTRY.

NUMBER OF STATIONS IN EACH TEMPERATURE GROUP.

STATES.	35°–40°	40°–45°	45°–50°	50°–55°	55°–60°	60°–65°	65°–70°	70°–75°	75°–80°
Colorado	2	8	16	14	..	..	..	..	..
Arizona	..	..	1	3	..	12	9	8	..
Washington	..	1	8	5	..	..	..	..	..
Wyoming	3	11	7		..	..	..	..	..
Idaho	1	3	4	6	1	..	..	..	..
Montana	1	12	4	..	..	..	..	..	..
New Mexico	..	..	2	3	5	3	1	..	..
Nevada	1	..	9	10	3	.	..	..	..
Oregon	..	1	6	2	..	..	..	..	..
Utah	1	1	14	14	1	..	..	..	..
California (South)	..	..	..	1	21	20	10	3	4
California (North)	..	..	1	8	13	30	7	..	..
Totals	9	37	72	66	44	65	27	11	4

YELLOW PINE.

NUMBER OF STATIONS IN EACH TEMPERATURE GROUP.

STATES.	40°–45°	45°–50°	50°–55°	55°–60°	60°–65°
Arizona	..	1	..	.	1
Washington	2	4	1	..	..
Oregon	1	1	7	..	..
California (North)	5	2	12	3	3
Totals	8	8	20	3	4

DESERT SPECIES.

NUMBER OF STATIONS IN EACH TEMPERATURE GROUP.

STATES.	45°–50°	50°–55°	55°–60°	60°–65°
New Mexico	..	2	..	..
Arizona	..	..	..	1
California (North)	..	..	5	18
California (South)	1	..	6	..
Totals	1	2	11	19

RED WOOD.

NUMBER OF STATIONS IN EACH TEMPERATURE GROUP.

STATE.	50°-55°	55°-60°
California	3	3

The table showing the average temperature of different classes of country is apparently of little significance, partly because of the irregular distribution of the stations, especially in certain of the timbered regions, and partly because there does not appear to be any characteristic difference of temperature in different regions. Because of the first of the above qualifications it is probable that the average temperature of the yellow-pine regions is too high, since most of the stations within this region are in the lower part of the timber-belt. The distribution of stations in the red-fir region is fairly uniform, and the temperature given in the table is probably not far from correct. The same is probably the case with the redwood region. Under the heading of "Open Country" are included the great plains, broad valleys, and desert regions generally, and the temperature of these regions differs widely in different parts of the country, from 42 degrees in Wyoming up to 65 degrees in the deserts of Arizona, and the average has little significance.

Classifying these stations in groups of five degrees of temperature each, it is seen that in the open country no less than 93 per cent. of the stations are found where the temperature ranges between 40 and 70 degrees. In the States of Wyoming and Montana there was no station with a temperature exceeding 50 degrees. In Colorado, Washington, and Oregon there was no station exceeding 55 degrees. On the other hand, in southern California stations are found ranging up nearly to 80 degrees, while there were none below 50 degrees.

The table relating to yellow pine shows that the greatest number of stations is found where the temperature is between 50 and 55 degrees, while the entire range of the species, as indicated by the stations, is from 40 to 65 degrees.

Nearly all the stations in the red-fir region are found between 50 and 55 degrees. Indeed, outside of this group the stations are but scattering.

In the redwood region all the stations are between 50 and 60 degrees.

Woodland shows a high temperature, nearly all the stations

being between 55 and 65 degrees—that is, at the highest temperatures represented.

The upper limit of tree growth, or the timber-line, is a matter of temperature, and is not difficult of definition. In the "American Journal of Science" for 1882, page 275, I published an article entitled "The Timber-Line," in which I showed that the mean annual temperature of the timber-line in the United States is one or two degrees below freezing-point. The data for this result are as follows:

Given the height of the timber-line in feet, the height and the mean annual temperature of a station at or near the base of a mountain, and the fact that the mean annual temperature diminishes about three degrees in each thousand feet of ascent, the calculation of temperature of the timber-line is a very simple matter.

The result above given, which is set forth fully in the article referred to, is corroborated by more recent and extended investigation, and the separate results show a range of only four or five degrees. The fact that in different parts of the country the timber-line species differ does not appear to affect the result, since the same figure is obtained for Mount Washington, New Hampshire, Mount Marcy, New York, the mountains of Colorado and Montana, the Sierra of California, and the Cascade Range of Oregon and Washington.

The conclusion reached, that the timber-line has a mean annual temperature of approximately 30 degrees, makes the location of this isotherm a simple matter.

RAINFALL.

States.	Average Rainfall in Inches.				
	Yellow Pine.	Fir.	Redwood.	Desert Species.	Open Country.
Arizona	23	..	..	15	9
Colorado	..	..	..	..	14
California (North)	44	..	44	30	18
California (South)	30	..	57	19	11
Idaho	24	..	..	..	12
Montana	21	..	..	..	15
New Mexico	..	..	..	20	11
Nevada	..	..	..	..	7
Oregon	31	56	..	..	13
Utah	..	..	..	16	11
Washington	21	56	..	..	15
Wyoming	..	..	..	..	12
Average rainfall of total stations	34	56	46	24	13

OPEN COUNTRY.

NUMBER OF STATIONS IN EACH RAINFALL GROUP.

STATES.	−10″	10″–15″	15″–20″	20″+
California	39	47	33	15
Wyoming	6	18	2	..
Nevada	20	3	1	..
Oregon	2	6	5	..
Washington	3	3	9	1
New Mexico	10	12	4	..
Arizona	22	14	3	..
Colorado	8	18	26	..
Montana	..	15	11	1
Idaho	3	10	1	1
Utah	15	13	7	.
Totals	128	159	102	18

YELLOW PINE.

NUMBER OF STATIONS IN EACH RAINFALL GROUP.

STATES.	−20″	20″–30″	30″–40″	40″–50″	50″–60″	60″–70″	70″+
Arizona	..	2	..	..	..	..	..
California	1	8	5	8	8	3	1
Montana	1	3	..	.	..	..	..
Washington	2	5	..	..	..	..	..
Oregon	1	5	3	2	..	..	..
Idaho	2	5	1	..	..	..	..
Totals	7	28	9	10	8	3	1

RED FIR.

NUMBER OF STATIONS IN EACH RAINFALL GROUP.

STATES.	−30″	30″–40″	40″–50″	50″+
Washington	3	7	7	13
Oregon	..	8	13	19
Totals	3	15	20	32

REDWOOD.

NUMBER OF STATIONS IN EACH RAINFALL GROUP.

STATE.	−30″	30″–40″	40″–50″	50″
California	1	7	4	5

DESERT SPECIES.

NUMBER OF STATIONS IN EACH RAINFALL GROUP.

STATES.	—20″	20″–30″	30″
California	13	25	16
New Mexico	2	1	..
Arizona	6	..	..
Utah	2	..	..
Totals	23	26	16

The data relating to rainfall are more definite and much more significant than those of temperature. The table presenting the average rainfall of the different regions shows that the average of the open country is 13 inches and that of the different States ranges from 7 inches in Nevada up to 18 inches in northern California. The average rainfall under which yellow pine grows, as indicated by these data, is 34 inches, but owing to the irregularity in the distribution of stations its true average should probably be somewhat greater. The different States show for yellow pine a range from 19 inches in Wyoming up to 44 inches in northern California. The average rainfall of the red fir in Oregon and Washington is 56 inches and that of the redwood is 46 inches. In both these cases the figures probably represent very closely the facts. Desert species, with an average of 24 inches for the entire West, shows a range among the States from 15 inches in Arizona up to 30 inches in northern California.

These rainfall stations have been classified in groups of ten inches of rainfall, or, in the case of open country, by five inches. For the open country this classification shows that nearly all the stations—indeed, 96 per cent. of them—have less than 20 inches of rainfall, which appears to indicate that where the rainfall exceeds 20 inches one may expect to find the country wooded. Nearly all the stations in which the rainfall exceeds 20 inches—*i. e.*, fifteen out of eighteen stations—are found in California, and many of them are in the upper part of the Sacramento Valley.

Of the stations in the yellow-pine country, nearly all—fifty-nine out of sixty-six—are found where the rainfall exceeds 20 inches. This appears to indicate that the lower limit of the yellow pine is at or just below 20 inches of rainfall. The upper limit is not clearly defined, owing, probably, to scarcity of stations in the higher country. In California one station at least is found

where the rainfall exceeds 70 inches, and there are twelve in which the rainfall exceeds 50 inches.

In the regions occupied by the red fir only three stations out of seventy are reported as having a rainfall less than 30 inches. This appears to indicate that the lower limit of the red fir is at or about 30 inches of rainfall. There is apparently no upper limit, the fir being found abundantly in regions where the rainfall exceeds 100 inches annually.

The redwood strip on the California coast includes but one station having a rainfall less than 30 inches, which appears to indicate that the isohyetal line of 30 inches is the lower limit of this species.

DRAINAGE MODIFICATIONS IN THE SOUTHEASTERN APPALACHIANS.

The following is an abstract of a paper by Prof. Douglas Wilson Johnson of the Massachusetts Institute of Technology which has just received one of the Walker prizes of the Boston Society of Natural History :

From time to time mention has been made of a capture of the former headwater portion of the Chattahoochee River, by the upper portion of the Savannah River, at the border between western South Carolina and northeastern Georgia. In the summer of 1905 the speaker spent several weeks in a study of the region in question. The results of this study appear to justify the following conclusions:

(1) The upper portion of the present Savannah River formerly flowed southwest through the Chattahoochee River into the Gulf of Mexico, but was diverted to the Atlantic drainage by a process of stream capture.

(2) The capture furnishes an example of what may properly be termed "remote capture," having occurred so long ago that much of the direct evidence has been obliterated.

(3) The capture resulted from the advantage enjoyed by the Atlantic drainage over the Gulf drainage, owing to the shorter course to the sea which streams of the former system traversed.

(4) Both the Tallulah and Chattooga Rivers (now tributary to the Savannah) occupy to-day the same general courses which they occupied before the capture, the combined waters of both streams having been diverted at the same time by a single instance of capture, which took place a short distance below their point of junction.